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FERTILIZERS.

CO-OPERATIVE EXPERIMENTING

AS A MEANS OF

STUDYING THE EFFECTS OF FERTILIZERS

AND THE

FEEDING CAPACITIES OF PLANTS.

BY PROF. W. O. ATWATER.

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DEPARTMENT OF AGRICULTURE,
Washington, D. C., March 27, 1882.

SIR: I submit for your consideration the following suggestions with regard to plants and fertilizers, which were laid before this department by Professor Atwater at the agricultural convention held here in January last.

I consider it very important that these suggestions should be put to a practical test, and I shall feel under great obligations if you will establish a series of experiments upon the plants and fertilizers herein enumerated, and will submit a report thereon to the department with as much care and elaboration as you can without interfering with your duties or with the work which you have assigned yourself.

Very respectfully,

GEO. B. LORING,
Commissioner of Agriculture.

CO-OPERATIVE EXPERIMENTING

AS A

MEANS OF STUDYING THE EFFECTS OF FERTILIZERS AND THE FEEDING CAPACITIES OF PLANTS.

BY PROF. W. O. ATWATER.

Farmers, from Canada to Texas, are spending millions upon millions of dollars every year for guano, fish scrap, ammoniated superphosphates, nitrate of soda, and the like. Ostensibly, they are buying the fertilizers at from \$20 to \$100 per ton. Actually, they are buying nitrogen at from 15 to 40 cents per pound. But need the farmer spend so much for nitrogen? Or might he use more with profit? These are questions that no professor of agriculture can answer. Indeed, no chemist or botanist to-day can so much as tell him how the different plants he cultivates stand related to nitrogen, for what ones he must buy it, and what ones he may use in his rotation to gather it from nature's stores and furnish it to him without money and without price save the cost of tillage.

The question of the nitrogen supply is only one of a great many whose solution is most urgently demanded. We must know how to feed our plants, or go without food ourselves. We need more light. Some must come from the laboratory and the greenhouse; some must be sought in the field.

Field experiments rationally planned, carefully carried out, faithfully reported, and interpreted with the aid of the most advanced science, will carry us far toward finding out many of these things which we so much want to know. If along with these we can have proper studies, chemical and physical, of the soils experimented upon, analyses of the plants produced, and in addition pot experiments whose conditions can be definitely known and controlled, and especially if we can work together we may hope for the information we need.

Five years ago, while director of the Connecticut Agricultural Experiment Station, I suggested some field experiments with fertilizers to be carried out by farmers for the purpose of studying the needs of their soils and the best materials to supply them. The outgrowth of these, in the form of extended series of experiments during four successive seasons, has been stated briefly in the *American Agriculturist*, and, in more detail, in the Reports of the Connecticut Board of Agriculture

for 1877, 1878, 1879, and 1880. The experiments of 1881 have not yet been published in detail, but a few of the more important results will be given herewith.

With the sets of experimental fertilizers were sent blanks on which any who should choose were invited to send reports of their experiments. Nearly three hundred experiments have been reported. They come from colleges, experiment stations, and individual farmers in all the States east, and from some west of the Mississippi, and from several of the British provinces. The quality of the work as indicated by the reports is most gratifying.

The experiments have been of two classes. The first, which may be called general experiments, are of a simpler sort, and intended primarily for soil tests, involve the use of eight or more different kinds and mixtures of fertilizing materials containing nitrogen, phosphoric acid, and potash. The second class, the "special nitrogen experiments", have been of more complicated character, and have had for their object the study of the feeding capacities of some of our more common cultivated plants, with special reference to the nitrogen supply.

It is to these latter experiments that attention is especially invited here.

THE FEEDING CAPACITIES OF PLANTS.

The experiments we are discussing bring us face to face with one of the most important problems with which agricultural chemistry has to deal, and at the same time throw some new light upon it. I refer to what may, perhaps, be most properly called the feeding capacities of plants, their power of gathering their supplies of food from soil and air, and the effects of the artificial supply of different ingredients of plant-food upon their growth.

A vast deal of experience in the laboratory and in the field bears concurrent testimony to the fact, though we are still deplorably in the dark as to how or why it is so, that different kinds of plants have different capacities for making use of the stores of food that soil and air contain. Of the ingredients of plant food in our soils, the most important, because the most costly, is nitrogen. Leguminous crops, like clover, do somehow or other gather a good supply of nitrogen where cereals, such as wheat, barley, rye, and oats would half starve for lack of it, and this in the face of the fact that leguminous plants contain a great deal of nitrogen, and cereals relatively little. Hence a heavy nitrogenous manuring may pay well for wheat and be in large part lost on clover.

NEED OF MORE INFORMATION.

Hitherto we have been compelled to rely mainly upon European investigations for our facts regarding the nutrition of plants and the action of manures. Our information is incomplete, and even the foremost teachers may give us wrong counsel.

Dr. J. B. Lawes, of Rothamsted, England, unquestionably the fore-

most field experimenter in the world, in writing, in 1873, to the treasurer of the Massachusetts Society for the Promotion of Agriculture, said: "The best possible manure for all graminaceous crops—wheat, barley, maize (corn), oats, sugar-cane, rice, and pasture grass—is a mixture of superphosphate and nitrate of soda. * * * Potash is generally found in sufficient quantities in soils, and the artificial supply is not required." In more than half of our experiments with corn, and in nearly all with potatoes, the crops have been materially aided by potash salts, and without potash in the fertilizer they have often failed. The mixture which Dr. Lawes regards as "the best possible manure" for corn was sometimes very useful and sometimes brought almost no return. The potash, which his experience in England led him to consider superfluous, was here, in many cases, the most necessary of all the fertilizing ingredients.

Several years ago the professor of agriculture of one of our leading agricultural colleges proposed a series of formulas for different crops. With the rest was one for corn, which, with a moderate proportion of potash and a small amount of phosphoric acid, supplied nitrogen at the rate of 64 pounds, and at a cost of over \$15 per acre. Later, a well-known writer upon agricultural science has enthusiastically advocated the culture of corn with chemicals, recommending for the purpose, and using in an extensive series of experiments upon his own farm, a fertilizer which supplied nitrogen at the rate of 90 pounds, and at a cost of \$18 to \$20 per acre. Both of these gentlemen thus assumed that to raise corn successfully would require large and costly supplies of nitrogen. The question whether corn can gather its own nitrogen, like clover, or demands an artificial supply, like wheat, whether it is an "exhausting" or a "renovating" crop, has been much discussed. Upon its answer depends the success of corn-growing in our older States. The experiments referred to bear emphatic testimony upon this point. The corn has almost uniformly refused to respond to nitrogen in fertilizers, and persists in getting on well without any artificial supply. But it has been largely benefited by phosphoric acid, and often by potash. The formulas above, with their large and excessively expensive amounts of nitrogen, would, in nearly every case, have involved great waste of both fertilizer and money.

EXPERIMENTS UPON THE EFFECTS OF NITROGENOUS FERTILIZERS.

One of the ways in which co-operative field experiments may aid in the solution of these problems may be illustrated by citing some of the details of the series of experiments upon the effect of nitrogen in fertilizers which were referred to above, and which have been performed by a number of professors in agricultural colleges and practical farmers, with what seems to me most gratifying success.

The specific questions to be studied may be stated thus:

1st. How do the plants experimented with get on with the "mineral" fertilizers, such as are supplied by superphosphates and potash salts?

2d. More especially, how do they respond to nitrogen when added, in different forms and amounts, to the mineral fertilizers?

3d. And finally, what inferences may we draw as to the feeding capacities of the plants, their power to gather their food from soil and air, and the effects of different materials upon their growth, especial reference being made to the nitrogen supply?

For the systematic study of these questions a special "nitrogen experiment" was devised in 1878, and conducted by several gentlemen. Similar series were repeated in 1879, and with some variations in 1880 and 1881.

The idea was to compare the effects of mineral fertilizers (superphosphate and potash salt) alone, and the same with nitrogen in different amounts and forms. The plan is explained in the following extract from a circular sent to the experimenters:

The Object of this experiment is to test the effects of nitrogenous fertilizers in different amounts and combinations upon the growth of the plant, and inferentially its capacity to gather its nitrogen from natural sources.

The Fertilizers.—The ingredients and amounts are such as are used in ordinary practice, phosphoric acid and potash being supplied in about the proportions that occur in a corn crop of fifty or sixty bushels, and nitrogen in one-third, two-thirds, and full amount in same crop.

Forms of Nitrogen.—The nitrogen is supplied as nitric acid in nitrate of soda; as ammonia in sulphate of ammonia, and as organic nitrogen in dried blood.

Quantities of Nitrogen.—The nitrogen is supplied at the rate of twenty-four pounds per acre in "one-third ration"; forty-eight pounds per acre in "two-thirds ration"; and seventy-two pounds per acre in "full ration".

Arrangement of Plots and Fertilizers.—The ingredients are supplied as:

Partial fertilizers,	{ Group I. Nos. 1—3. each by itself. }	} Thus testing the effects of ingredients separately, and capacity of soil.
	{ Group II. Nos. 4—6. Two by two. }	
Complete fertilizers	{ Group III. Nos. 7—9. Nitrogen as nitric acid }	{ Nitrogen in one-third, two-thirds, full ration.
	{ in nitrate of soda. }	
	{ Group IV. Nos. 10—12. Nitrogen as ammonia }	
	{ in sulphate of ammonia. }	
	{ Group V. Nos. 13—15. Nitrogen as organic }	
	{ nitrogen in dried blood. }	

The fertilizers were supplied, in part at cost, and in part gratuitously, by the Mapes Formula and Peruvian Guano Company of New York. Especial thanks are due to Mr. C. V. Mapes, without whose interest and enthusiasm, as well as counsel and substantial help, the enterprise could not have succeeded as it has.

The full details of the experiments are to appear in a report of the United States Department of Agriculture. The tables herewith give an outline of results of some of the experiments of the last season and will serve as illustrations. The figures are, however, much condensed and many interesting details are omitted.

TABLE I gives the results of several experiments with cotton, corn, and potatoes. The unfavorable weather which affected the majority of the experiments, has reduced the yield materially in most of these. In several the effects of unevenness of soil are manifest; on some the supply of available plant food in the soil was evidently so great as to obscure the action of the fertilizers. Those of Mr. Newton with corn

and Mr. Manning with clover, show marked exceptions to what seems to be the common rule, that these crops are not greatly aided by nitrogenous fertilizers. Indeed, all illustrate forcibly our need of more experimenting.

TABLE II shows an experiment on an older and slightly different schedule. It is interesting both because of its sharply-defined results and as an illustration of the excellent work ordinary farmers do in this line.

TABLE I. NITROGEN EXPERIMENTS, 1881.

I. PROF. W. C. STUBBS, Alabama Agricultural and Mechanical College, Auburn, Ala.:

Soil—Worn-out pasture; level, upland, sandy, light, well-drained.

Subsoil—Reddish yellow clay. *Weather*—Dry and unfavorable.

II. EDWARD HICKS, Old Westbury, N. Y.:

Soil—Level, sandy loam, light, dry. *Subsoil*—Yellow loam. *Previous crop*—Corn. *Weather*—Dry and unfavorable.

III. PROF. C. L. INGERSOLL, Purdue University, La Fayette, Ind.:

Soil—Upland, level, black, similar to prairie, sticky when wet, bakes when dry; dry, well drained. *Subsoil*—Gravel. *Previous crop*—Corn. *Weather*—Very dry and unfavorable.

IV. PROF. SAMUEL JOHNSON, Michigan Agricultural College, Lansing, Mich.:

Soil—Level, upland, sandy loam, light, drained dry. *Subsoil*—Gravelly. *Previous crop*—Corn. *Weather*—Dry, cold, unfavorable.

V. W. C. NEWTON, Durham, Conn.:

Soil—Old meadow, hill land, dark loam. *Subsoil*—Moist. *Weather*—Unfavorable.

VI. J. W. PIERCE, West Millbury, Mass.:

Soil—Worn-out grass land, upland, nearly level, clay loam, light, dry. *Subsoil*—Gravelly, but some clay. *Weather*—Cold and unfavorable.

VII. C. E. THORNE, farm manager, Ohio State University, Columbus, O.:

Soil—Level, upland, clayey loam, "drift formation" from Huron shale, compact, wet before draining. *Subsoil*—Similar to surface soil, retentive. *Previous crop*—Corn, with stable manure. *Weather*—Severe drouth.

VIII. J. M. MANNING, Taunton, Mass.:

Soil—Upland, sandy loam, loose. *Subsoil*—Yellow sand. *Previous crops*—Potatoes and corn. *Weather*—Unfavorable.

TABLE I.—EFFECTS OF NITROGENOUS FERTILIZERS.

I. Professor STUBBS, Alabama, COTTON.
 II. Mr. HUGES, New York, CORN.
 III. Professor EXCE, Indiana, CORN.
 IV. Professor JOHNSON, Michigan, CORN.

V. Mr. NEWTON, Connecticut, CORN.
 VI. Mr. PIERCE, Massachusetts, CORN.
 VII. Mr. THORNE, Ohio, CORN.
 VIII. Mr. MANNING, Massachusetts, CLOVER.

Fertilizers and produce per acre.

	I. Cotton.	II. Corn.	III. Corn.	IV. Corn.	V. Corn.	VI. Corn.	VII. Corn.	VIII. Clover.
	<i>Lbs.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Lbs.</i>
0. No manure	587	16.3	38.2	44.7	12.5	10.3	40.0	480
1. Nitrate of soda, 150 pounds	85.5	26.0	53.1	53.1	22.5	11.7	44.3	77.0
2. Superphosphate, 300 pounds	1,162	22.8	36.4	51.2	13.8	16.0	48.6	1,200
3. Muriate of potash, 150 pounds	1,564	34.5	34.5	52.0	15.0	17.7	48.6	940
4. Nitrate of soda, 150 p. mds.	1,599	24.5	33.6	61.6	23.8	14.3	50.3	1,080
5. Superphosphate, 300 pounds	932	29.5	34.5	43.6	23.8	23.0	44.9	560
6. Muriate of potash, 150 pounds	1,219	28.2	34.5	59.0	13.8	34.6	52	1,140
7. Mixed mineral fertilizers (as No. 6)	1,541	29.0	37.3	58.8	23.3	34.0	49.1	1,200
8. Mixed mineral fertilizers	1,404	33.8	32.5	55.6	41.7	35.7	45.7	1,460
9. Nitrate of soda, 300 pounds	1,242	31.5	33.1	49.1	56.7	41.4	47.4	1,480
10. Nitrate of soda, 450 pounds	3,115	30.0	33.4	56.7	16.3	37.7	46.0	1,660
6a. Mixed mineral fertilizers (as No. 6)	1,116	27.8	36.1	55.7	28.5	39.4	41.7	1,880
10. Sulphate of ammonia	1,265	30.8	38.4	58.9	42.5	40.3	42.3	2,000
11. Mixed mineral fertilizers	1,162	32.5	34.0	50.4	48.3	39.4	43.4	2,400
12. Sulphate of ammonia	1,162	29.0	35.7	51.0	28.6	28.6	48.3	1,440
6b. Mixed mineral fertilizers (as No. 6)	1,357	37.6	34.0	49.4	28.8	35.4	41.1	1,620
13. Dried blood, 25 pounds	1,300	36.3	34.5	51.6	33.8	37.0	41.4	1,940
14. Mixed mineral fertilizers	1,127	35.2	33.4	61.4	49.6	39.0	39.4	2,420
15. Mixed minerals (as No. 6)	1,127	39.7	33.4	57.1	20.6	40.9	40.9	1,200
6c. Mixed minerals (as No. 6)	449	16.5	33.1	31.7	13.8	35.4	35.4	1,500
16. Farm manure								800
6d. No manure								

In Professor Stubbs's experiment three plots, not mentioned in the table, had "mixed minerals" with cotton-seed meal in quantities to supply nitrogen in the same amounts as in the nitrate of soda, sulphate of ammonia, &c. The yields were, with $\frac{1}{2}$ ration 1,233.5 pounds, with $\frac{3}{4}$ ration 1,518 pounds, and with full ration, 1,345 pounds per acre.

TABLE II.—EFFECTS OF NITROGENOUS FERTILIZERS.

Experiments with oats and potatoes in 1831. By Mr. Charles Fairchild, of Middletown, Conn.

[Soil, dark loam, lean subsoil, moist; had oats in 1877, rye in 1878, grass in 1879, and corn fertilized as below in 1880.]

	Kind and amount of fertilizers per acre.	Yield per acre.				Increase per acre.				Cost of fertilizers, &c.	Preliminary results.			
		Oats.		Pota- toes.	Oats.		Pota- toes.	Value of in- crease.			Gain.			
		Grain.	Straw.		Grain.	Straw.		Oats.	Pota- toes.		Oats.	Pota- toes.		
Bush.	Lbs.	Bush.	Lbs.	Bush.	Lbs.	Bush.	Lbs.							
0	No manure	26.9	1,180	28.0	1,180	11.3	627	13.3	627	\$6.00	\$9.75	\$9.98	\$3.95	\$3.98
1	Nitrogen mixture, 150 pounds.	34.1	1,820	42.0	1,820	6.9	607	27.3	1,820	6.00	7.42	20.48	1.42	14.48
2	Superphosphate, 300 pounds	33.8	1,800	36.0	1,800	4.4	527	31.3	1,800	3.75	5.50	23.48	1.75	19.73
3	Muriate of potash, 150 pounds	31.3	1,720	60.0	1,720	25.0	1,467	66.0	1,720	12.00	22.55	49.50	10.55	27.50
4	Nitrogen mixture, 150 pounds, and superphosphate, 300 pounds	51.9	2,630	94.7	2,630	15.6	967	93.3	2,630	9.75	14.40	29.48	4.65	19.73
5	Nitrogen mixture, 150 pounds, and muriate of potash, 150 pounds	42.5	2,160	68.0	2,160	6.9	1,087	62.0	2,160	9.75	10.20	46.50	5.55	36.75
6	Superphosphate, 300 pounds and mur. of pot., 150 pounds, "mixed minerals"	33.8	2,500	124.7	2,500	27.5	2,307	96.0	2,500	15.75	28.97	72.00	13.22	54.25
7	Mixed minerals (as No. 6), 450 pounds, and nit rate of soda, 150 pounds	54.4	3,800	138.7	3,800	32.5	2,667	110.0	3,800	21.75	33.88	82.50	12.13	60.75
8	Mixed minerals, 450 pounds, and nitrate of soda, 300 pounds	59.4	4,380	140.0	4,380	32.5	3,107	91.3	4,380	27.75	36.72	88.40	8.77	40.65
9	Mixed minerals, 450 pounds, and nitrate of soda, 450 pounds	59.4	4,380	140.0	4,380	32.5	3,107	91.3	4,380	27.75	36.72	88.40	8.77	40.65
10	Mixed minerals (as No. 6), 450 pounds	36.3	1,760	94.0	1,760	34.4	567	63.3	1,760	9.75	8.56	48.96	1.19	39.23
11	No manure	27.5	1,240	46.7	1,240	25.0	1,947	94.0	1,240	15.75	25.43	70.50	9.08	54.75
12	Mixed minerals, 450 pounds, and nitrogen mixture, 150 pounds	51.9	3,140	122.7	3,140	28.8	2,187	116.0	3,140	21.75	28.53	87.00	7.10	65.25
13	Mixed minerals, 450 pounds, and nitrogen mixture, 300 pounds	55.6	3,380	144.7	3,380	32.5	2,587	116.0	3,380	27.75	33.40	87.00	5.65	59.25
14	Mixed minerals, 450 pounds, and nitrogen mixture, 450 pounds	59.4	3,780	144.7	3,780	32.5	2,587	116.0	3,780	27.75	33.40	87.00	5.65	59.25
15	Mixed minerals (as No. 6), 450 pounds	33.8	1,760	110.0	1,760	6.9	567	81.3	1,760	9.75	7.18	60.98	2.77	51.23
16	Mixed minerals, 450 pounds, and sulphate of ammonia, 255 pounds	61.9	3,700	135.3	3,700	35.0	2,507	106.6	3,700	21.75	34.29	79.55	12.54	58.20
17	Mixed minerals, 450 pounds, and dried blood, 450 pounds	53.8	3,680	134.7	3,680	26.9	1,887	105.0	3,680	21.75	26.10	79.50	4.35	57.75
18	Peruvian guano, 450 pounds, and muriate of potash, 150 pounds	54.4	2,980	133.3	2,980	27.5	1,787	104.6	2,980	21.75	25.85	78.45	4.10	56.70
19	Mixed minerals (as No. 6), 450 pounds	35.0	1,710	96.0	1,710	8.1	567	67.3	1,710	9.75	7.87	50.48	1.88	40.73
20	No manure	26.3	1,120	29.3	1,120	4.4	487	25.3	1,120	3.00	5.23	18.18	2.33	15.98
21	Bone, 150 pounds	31.3	1,680	74.0	1,680	8.1	767	45.3	1,680	5.50	9.07	23.98	4.57	28.48
22	Bone, 150 pounds, and muriate of potash, 100 pounds	35.0	1,960	74.0	1,960	8.1	767	45.3	1,960	5.50	9.07	23.98	4.57	28.48
23	Same as 22, and sulphate of ammonia, 100 pounds	45.6	1,980	74.0	1,980	18.8	787	45.3	1,980	10.75	15.03	23.98	4.28	28.48

The plots were parallel strips of eight square rods each. In 1880 corn was planted over the whole field. In 1881 the whole was divided into halves by a line crossing the plots, and one-half devoted to oats and the other half to potatoes. Mr. Fairchild proposes to follow with wheat and grass, thus running the experiment through a regular rotation of several years, the same fertilizers being applied to the same plots year after year, while the crops succeed each other as in ordinary farm practice. The cost of the fertilizers includes \$5 per ton for freight and applying. Potatoes are estimated at 75 cents per bushel, oats at 55 cents, and oat straw at \$12 per ton, which are fair rates for the region and season.

The variety of results in the different experiments is very striking. Mr. W. I. Bartholomew, of Putnam, Conn., has been conducting the nitrogen experiments with corn and potatoes for three years. In every trial every plot which has received phosphoric acid has given a more or less satisfactory return, and every one without phosphoric acid has failed. Nitrogen and potash have each increased the yield of corn, but neither has brought enough increase to pay its cost, and the loss has been larger or smaller as more or less was used. Potatoes, on the other hand, have responded profitably to all the ingredients.

Mr. C. Sage, of Middletown, Conn., has had a very different experience. Nitrogen has proved as inefficient on his land as on Mr. Bartholomew's. Phosphoric acid, which Mr. Bartholomew finds so effective, helps him but little, while potash is decidedly the regulating ingredient, the corn responding uniformly and largely to every application of potash salt. One hundred and fifty pounds per acre of muriate of potash, costing \$3.50, makes the difference between corn so poor as to be hardly worth the husking, and 60 bushels or more of beautiful shelled corn and a fine growth of stalks.

In the experiment of Mr. C. Newton, of Durham, Conn., given in Table I, we have a still different result. Potash is as useless as in Mr. Bartholomew's experiment. Phosphoric acid does no more good here than with Mr. Sage. But the nitrogen to which both these gentlemen's corn paid so little heed is on Mr. Newton's soil uniformly efficient. The corn responds largely and profitably to nitrogen in every form and on every plot, and the yield rises and falls regularly with the amount of nitrogen applied; I should add that in each of these cases the results are those not of a single, but of two or three years' trials. Mr. Newton's experience, however, seems to be an exception and an unusual one. Instances in which the nitrogen is absolutely harmful are much more frequent. Professor Thorne's in Table I is such an one. The corn here suffered from very severe drought, but Professor Thorne writes me that he has observed the same thing in favorable seasons, and several other reports tell the same story. Mr. J. W. Sanborn, the well-known farm superintendent and experimenter of the New Hampshire Agricultural College, has a case in which sulphate of ammonia helped the corn materially the first season, did no good the second, and "utterly demoralized" it the third.

On soils that are rich, or even in only fairly good condition, nitrogenous fertilizers, like other manures, often show very little effect. Such seems to be the case in Professor Henry's experiment in Table I.

EFFECTS OF NITROGENOUS FERTILIZERS UPON CORN.

Estimating a bushel of corn, with its cobs and stalks, to contain $1\frac{1}{2}$ of nitrogen, and to be worth 80 cents, the effects of the nitrogenous fertilizers in the special and in the general experiments may be summarized as follows, remembering that the superphosphate and potash salt,

"mixed minerals," supplied the amounts of phosphoric acid and potash in a crop of not far from 55 or 60 bushels, which would also contain about the 72 pounds of nitrogen.

In the general experiments of the mixture of 300 pounds superphosphate and 200 pounds muriate of potash brought on the average of fifty-three experiments, about 43½ bushels of shelled corn per acre. The special experiments, however, seem to me a fairer test of what the fertilizers may do, because, while made in all sorts of weather and on worn-out soils, they were nearly all on soils and in latitudes fit for corn, as many of the general experiments were not. In these the mixture of 300 pounds superphosphate and 150 pounds of potash salt, which can be bought for \$8.25, brought, on the average, 43 bushels of shelled corn per acre. Omitting Mr. Newton's experiment, the results of which are very exceptional, the average is 44½ bushels.

The experiments of the four seasons bear almost unanimous testimony to two things: The corn was helped but little by nitrogen in the fertilizers; and it gathered a good deal from natural sources. The increase of crop and of nitrogen in the crop will appear more clearly if we look at it another way.

In number of trials.	With nitrogen.		The average increase of corn was.	The increase of nitrogen in the crop was.
	Amount per acre.	Contained in crop of—		
	<i>Pounds.</i>	<i>Bushels.</i>	<i>Bushels.</i>	<i>Pounds.</i>
95	24	18	3.6	4.8
76	48	36	5.3	7.1
42	72	54	6.6	8.8

Or, estimating the results in dollars and cents :

In trials, total number.	With nitrogen, amounts.	Costing.	The nitrogen paid for itself in trials.	The nitrogen failed to pay for itself in trials.	The average loss in the several trials was.
95	24 lbs.	\$5 50	21	74	\$2 62
76	48 lbs.	11 00	13	63	6 76
42	72 lbs.	16 50	4	38	11 22

The only cases in which the largest rations were profitable were in the experiments of Mr. Newton.

The above calculations of pecuniary loss and gain of course apply only to those regions where corn is dear. But even at these rates the nitrogen increased the crop enough to pay its costs in only 38 trials out of 213. The pecuniary loss rose and fell with the amount of nitrogen used. With mineral fertilizers alone the crop gathered, by the above estimates, some 60 pounds of nitrogen per acre.

The important fact, however, is this: The corn plant has in these trials shown itself capable of getting on and bringing fair yields with small

amounts of the less costly mineral fertilizers, even in the worn-out soils of the Eastern States. With this help it has gathered its nitrogen from natural sources, and holds it readily to be fed out on the farm and returned in the form of manure for other crops. In other words, the experiments thus far imply that corn has, somehow or other, the power to gather a great deal of nitrogen from soil or air, or both; that in this respect it comes nearer to the legumes than the cereals; that, in short, corn may be classed with the "renovating" crops. If this is really so, and this can be settled only by continued experimenting, then our great cereal, instead of being simply a consumer of the fertility of our soils, may be used as agent for their restoration.

FEEDING CAPACITIES OF OTHER CROPS.

The results of the experiments with other crops were briefly summarized in an account given in the last report of the Connecticut board of agriculture, as follows:

Taking all in all, the potatoes responded well to the superphosphate, the potash salt, and the nitrogenous fertilizers, and the "complete fertilizer" has been most profitable in almost every case where the weather permitted fair growth. None of the other crops, except, perhaps, turnips, have shown such uniformly beneficial results from all the materials.

The experiments indicate very decidedly that the potato plant differs from many others in respect to the effect of these fertilizing materials upon its growth, and imply that it has less capacity than corn for gathering an adequate supply of food from natural sources. It seems to demand a full and immediately available supply of nourishment for its successful growth.

Concerning the other crops, the data at hand are too meager to warrant any general conclusions. * * * In general, however, the experiments accord with the common notion that makes superphosphate almost a specific for turnips. But they imply that even when the superphosphate is supplied in abundance, the turnip is not usually able to gather enough of the other materials for a full yield unless they are close at hand in readily available forms.

EXPERIMENTS WITH COTTON.

Professor Stubbs' experiment with cotton is extremely interesting. Phosphoric acid has great, and potash very little, effect. Nitrogen increases the crop, but that in cotton-seed meal is as useful, or more so, than in the other and more costly materials, nitrate of soda, sulphate of ammonia, and dried blood. This is only one of a number of experiments which Professor Stubbs has made, upon whose results, added to his general experience, he bases a number of important conclusions, among which are the following:

1. Our [Alabama] soils, which result from the disintegration of metamorphic rocks, principally feldspathic and hornblendic, need a little nitrogen, much phosphoric acid, and no potash for cotton.
2. Our great want, and it seems to prevail through the older cotton States (except the black cretaceous belt of Alabama, which has not been thoroughly tested), is soluble phosphoric acid. On worn-out soils a small amount of nitrogen is required. A fertilizer with 3 per cent. of nitrogen and 10 per cent. of soluble phosphoric acid, meets the demand very well.

3. Phosphoric acid hastens and nitrogen retards the maturity of the crop.

4. Cotton seed and cotton-seed meal are as effective as dried blood, sulphate of ammonia, nitrate of soda, or other nitrogenous fertilizers, and far cheaper and more economical.

To what extent and under what conditions such principles as these are applicable in the culture of cotton and other crops, are matters of vital importance in Southern agriculture. The usefulness of systematic experiments to test them needs no argument.

EFFECTS OF PHOSPHORIC ACID IN DIFFERENT FORMS OF COMBINATION.

The nitrogen supply is only one of the many questions whose solution is of vital importance to our agriculture. The relations of phosphoric acid, potash, and other ingredients of plant food, whose lack in our soils we seek to supply, at great expense, with phosphates and potash salts, demand equally full and thorough study.

Treating the insoluble phosphate of bone or mineral phosphate with acid to make superphosphate is expensive. Soluble phosphoric acid costs us from 12 to 15 cents or more per pound, while we can buy it in the insoluble forms for from 4 to 6 or 7 cents. The general theory is that superphosphate is necessary, but still, somehow or other, many of us have the feeling that, in many cases at least, the cheaper insoluble phosphates would do as well; that fine grinding might serve instead of superphosphating; and that there are many cases in which the cheap rock phosphates might replace the dearer bone manure. If so, the saving would be immense.

The Aberdeenshire Agricultural Association of Scotland, through Mr. Thomas Jamieson, F. C. S., its chemist, has been for several years past conducting an extended system of experiments in which have been studied, with other things, the effects of phosphoric fertilizers of different sorts, alone and associated with nitrogen.

The results of several years work on five typical varieties of Aberdeen soil in the ordinary state of cultivation are summarized by Mr. Jamieson in the statements.

1. That phosphates of lime decidedly increase the turnip crop, but that farmers need not trouble themselves to know whether they are of animal or mineral origin.

2. That soluble phosphate is not superior to insoluble phosphate to the extent that is generally supposed.

3. That nitrogenous manures have little effect on turnips used alone, but when used with insoluble phosphates increase the crop; that the addition of nitrogen to soluble phosphates does not seem to increase the solid or dry matter in the crop; that there is no material difference between the effects of equal quantities of nitrogen in nitrate of soda and in sulphate of ammonia.

4. That fineness of division seems nearly as effective in assisting the braird and increasing the crop as the addition of nitrogenous manures. Hence the most economical phosphoric manure for turnips is probably insoluble phosphate of lime, from any source, ground down to an impalpable powder.

Mr. G. Clendon, jr., of Buckner's Station, Va., who has carried out a series of the "general" experiments above referred to, and taken the opportunity to test finely-ground South Carolina phosphate alongside the dissolved bone-black, obtained with the raw phosphate a yield larger than with superphosphate or stable manure, and nearly as large as with the complete fertilizer. The testimony of a single experiment, of course, must always be questioned; but Mr. Clendon's results have the regularity that characterizes uniform land, and seem to be borne out by other experiments and his general experience. He writes:

My experiments have been carried on over ten years. In every year the good effect of the raw phosphate was apparent. * * * The soil is a decomposed gneiss, uniformly poor, and is a fair sample of hundreds of square miles lying between the base of the Blue Ridge and tide-water in Virginia. * * * I think the experiments should be repeated over a wider country.

On the other hand, it is a familiar fact that in the neighborhood of Charleston, S. C., where the raw phosphate is obtained, its use in the raw state has not become general, and that many attempts elsewhere to introduce insoluble phosphates have failed. When, where, and why the different forms of phosphoric acid are in place, are problems that demand thorough investigation.

WHAT IS NEEDED FOR SUCCESSFUL FIELD EXPERIMENTING.

Unless I greatly err, one of the chief causes of the failure of so much of the honest and thorough field experimenting that has been done, to accomplish its purpose has been that the questions have been too complex, while the work has not been prosecuted far enough to make it all complete.

It is by selecting specific and narrow questions, and working at them systematically and continuously, that we shall secure the most valuable results. There has been too much firing at random. We need to choose proper points of attack, be sure of our aim, and concentrate our fire until a breach is made.

CO-OPERATIVE EXPERIMENTING.

And we need not only to work rightly, but to work together. Experiments with a common object on a common plan, conducted by intelligent, careful investigators, in different places, under different but accurately observed and recorded conditions, are needed to bring the results which scientific agriculture so pressingly demands.

A letter from Professor Henry, of the agricultural department of the University of Wisconsin, says most aptly, "What we most need is *union*," and dwells upon the importance of co-operative field experiments with fertilizers, experiments which shall be "*far-reaching*" in their character.

Mr. Sanborn, of the New Hampshire Agricultural College, in alluding to the fact that most of our agricultural science hitherto has come from Europe, and that we need facts and principles of our own, says of the

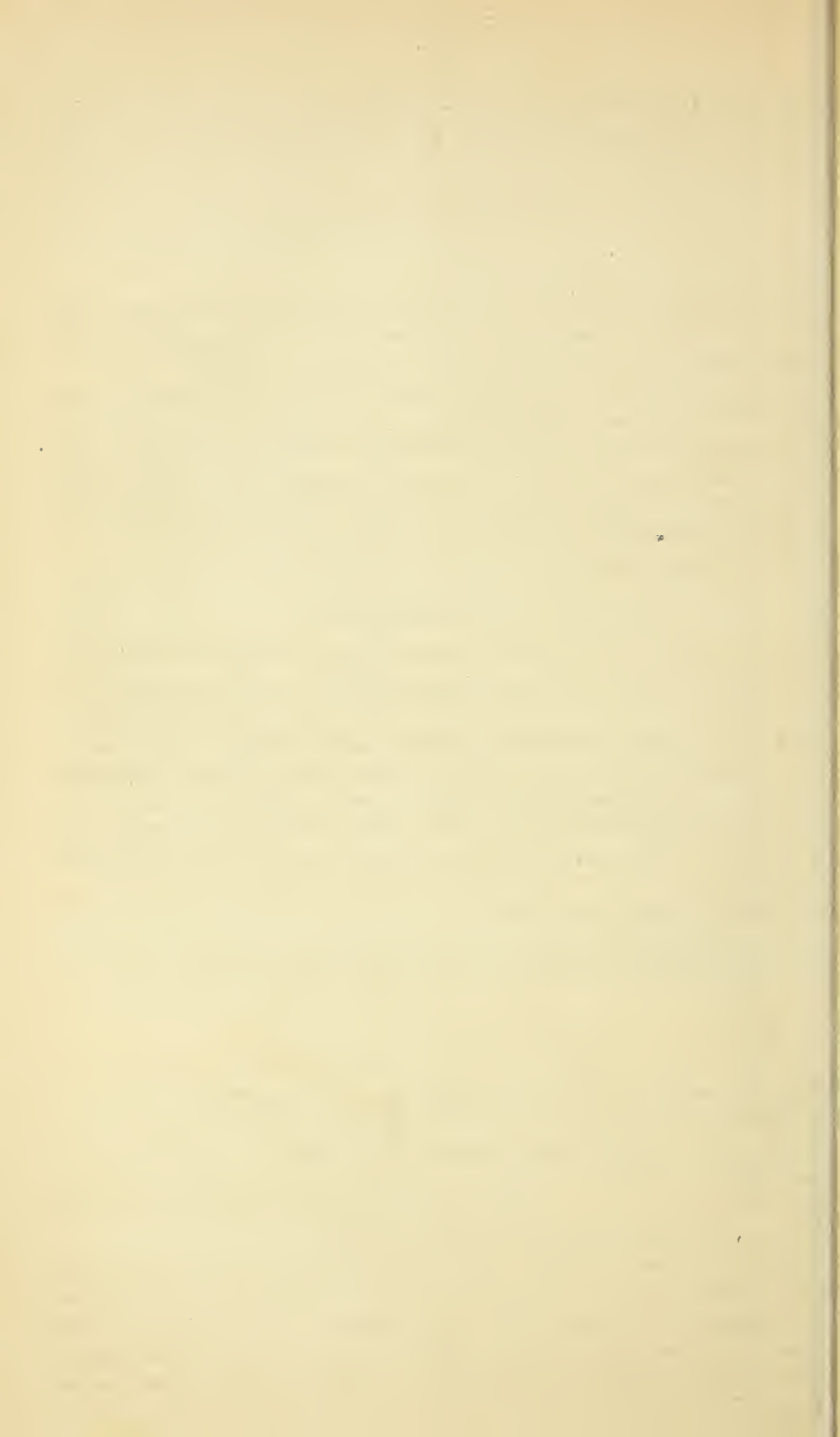
work of field experimenting with fertilizers: "It is of incalculable importance to the country," and adds: "The co-operative plan is the only right thing if quick and reliable work is to be done." And unless I greatly err, these gentlemen, who, with numerous others, are showing their faith by their works, are expressing in the words just quoted a general sentiment of the men who to-day are doing most to promote agricultural science in this country.

Now it seems to me that the way to co-operate is to co-operate. The way to get on is to "stay not upon the order of your going, but go." Go wisely, carefully, rationally, slowly if need be—but go.

The colleges and experiment stations of nine States, and several prominent farmers of the same and other States, have already commenced work on the schedule above explained. Six other colleges and stations have made arrangements to commence the same experiments this season, and three others are experimenting on the same question of the effects of nitrogenous fertilizers, though on somewhat different plans.

Several State agricultural reports show that the same enterprise is being considered by other official bodies as well. The secretary of the Ohio Board of Agriculture, Mr. Chamberlain, in his last report devotes a number of pages to accounts of the nitrogen experiments referred to, and suggests the study of the nitrogen supply for wheat on typical soils in his State. The last report of the commissioner of agriculture of Virginia recommends similar experiments in that State. Several other State organizations are taking steps in the same direction. Besides all these, there are numbers of intelligent farmers throughout the whole country who are able and will be more than willing to contribute most efficient work. The experiments above cited suffice to prove this beyond all doubt.

With the assured co-operation of so many representative men, including really the majority of the best-known experimenters in the country, the feasibility of co-operative experimenting is no longer a question.



APPENDIX.

In organizing a system of co-operative experimenting, to which the above address is devoted, one great need is an official and influential center, whence suggestions and plans for work may emanate, and where reports of results may be collated, arranged, and published, and with whose wise aid all can work together. By the espousal of the enterprise by the Agricultural Department at Washington, under its present very efficient management, this want is most happily met. And nothing could be more auspicious for such a union between the department and the best experimenters of the country than the discussions and action of the late convention.

PLANS FOR EXPERIMENTS.

In accordance with a request from the Commissioner of Agriculture, I have undertaken, with the aid of several well-known workers in this line, to prepare some plans for experiments; doing so, however, with the feeling that what is wanted is not detailed and inelastic schedules, but rather, outlines which each experimenter can fill in as seems to him most advisable. Every man knows his own circumstances, and every intelligent worker has valuable ideas of his own, which others have not. It seems to me that the most effective system will be one which will enable each to develop his own ideas, while we all work together and contribute our results to the common fund.

KIND OF INVESTIGATIONS THAT ARE NEEDED.

To get the most complete results we need:

- I. Field experiments, to include—
 - a. The culture of plants on plots of land treated with different manures, and careful weighings and measurements of produce.
 - b. Where practicable, chemical and physical studies of the soil.
 - c. In many cases, chemical analyses of the plants.
- II. Pot experiments, in which the conditions can be definitely known and controlled, and the needed studies of soil and plants be carried out with equal or greater convenience and accuracy.

Indeed, it is safe to say that there ought to be in the various sections of the country chemical and physical surveys of the land in the behalf of agriculture, as there have been topographical and geological surveys in the behalf of other industries and interests. And in fact this is precisely the direction in which we are tending in this experimental work.

PLANS FOR FIELD EXPERIMENTS.

The subjects proposed at the Washington convention for co operative experiments were:

1. The supply of nitrogen to plants.
2. The action of phosphoric acid in different forms of combination and in different fertilizing materials upon the growth of plants.

Practically, so far as field experiments are concerned, these two subjects reduce themselves to the study of the action of nitrogenous and phosphatic fertilizers.

The first thing, then, will be to see what materials are to be employed.

Since similar questions regarding potash will naturally arise, it may be well to include brief suggestions regarding potassic fertilizers. Of course sulphuric acid, lime, and magnesia could be treated in like manner if it should hereafter become desirable.

QUANTITIES OF MATERIALS TO BE USED.

To decide what quantities of materials will be best for the purpose is not easy, because of the lack of the very data for which the experiments are, in part, to be made. Neither the proportions which occur in any crops, nor those in farm manures, could well serve as a standard. Probably the best plan will be to endeavor to select, as extremes, the smallest and the largest quantities that general experience has brought into ordinary use, and arrange intermediate quantities at proper intervals between.

Nitrogen.—A dressing of 450 pounds of nitrate of soda per acre is probably as large as would be apt to be used in this country, in ordinary practice, on ordinary crops. At the same time it is no more than has been found profitable in previous nitrogen experiments, and is perhaps as small as would be advisable for the maximum. At 16 per cent. it would contain 72 pounds of nitrogen.

Three hundred pounds of an ammoniated superphosphate with 3 per cent., or 9 pounds, of nitrogen, is not an unusual dressing per acre. As little as 200 pounds, with only 6 pounds of nitrogen per acre, is a common quantity for cotton, and indeed, for other crops, when applied in the hill or drill or as a supplement to other manures. Six pounds of nitrogen is a very small quantity for an acre of land. Twelve pounds, which would be contained in 75 pounds of nitrate of soda, would seem to be little enough. Still, it will be well to provide for as small an amount as is ordinarily used.

In arranging the rations it would seem best to make the difference between the smaller rations less than that between the larger ones. In the previous nitrogen experiments, three rations, "one-third," "two-thirds," and "three-thirds," with 24, 48, and 72 pounds of nitrogen per acre, respectively, have been employed. Prefacing these by a "one-twelfth" ration of 6 pounds, and a "one-sixth" ration of 12 pounds, we shall have a series of five:

Nitrogen rations.

- a. One-twelfth ration: Nitrate of soda, 38 pounds, with 6 pounds of nitrogen.
- b. One-sixth ration: Nitrate of soda, 75 pounds, with 12 pounds nitrogen.
- c. One-third ration: Nitrate of soda, 150 pounds, with 24 pounds nitrogen.
- d. Two-thirds ration: Nitrate of soda, 300 pounds, with 48 pounds nitrogen.
- e. Full ration: Nitrate of soda, 450 pounds, with 72 pounds nitrogen.

Of this list, either all or part may be used. Thus on soils or for crops where smaller quantities are in place, *a. b.* and *c.* could be employed. Where more nitrogen is wanted, *c. d.* and *e.* would be better. If, as is not impossible, experience should show that the smaller rations are too small to be useful, it will be a very simple matter to omit them.

Phosphoric acid.—One hundred pounds of a superphosphate with 16 per cent. $P_2 O_5$ is as little as would be often used on an acre, while 600 pounds with 96 pounds of $P_2 O_5$ would be a large dressing. In view of the fact that general experience has led to the employing of much larger quantities of phosphoric acid than of nitrogen, the proportions within this range would be none too large to go with those of nitrogen suggested. Doubtless a series of four rations arranged as below would suffice.

Phosphoric acid rations.

- a. One-sixth ration: 100 pounds superphosphate with 16 pounds phosphoric acid.
- b. One-third ration: 200 pounds superphosphate with 32 pounds phosphoric acid.
- c. Two-thirds ration: 400 pounds superphosphate with 64 pounds phosphoric acid.
- d. Full ration: 600 pounds superphosphate with 96 pounds phosphoric acid.

Potash.—Many of the popular fertilizing mixtures are calculated to supply very small quantities of potash, not over 17 pounds per acre, while 200 pounds of muriate of potash are often used for a dressing. Taking these as extremes and dividing as before we shall have—

Potash rations.

- a. One-sixth ration: 33 pounds muriate of potash with 17 pounds potash.
- b. One-third ration: 67 pounds muriate of potash with 33 pounds potash.

c. Two thirds ration: 123 pounds muriate of potash with 67 pounds potash.

d. Full ration: 200 pounds muriate of potash with 100 pounds potash,

Putting the above forms together we have rations as follows:

	Nitrate of soda.	Superphosphate.	Muriate of potash.	Nitrogen.	Phosphoric acid.	Potash.
	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.
One-twelfth ration	38			6		
One-sixth ration	75	100	33	12	16	17
One-third ration	150	200	67	24	32	33
Two-thirds ration	300	400	133	48	64	67
Full ration	450	600	200	72	96	100

DUPLICATION OF TESTS.

A very great, if not the greatest, obstacle to the success of field experiments is the unevenness of soils. The variations in the produce of different plots of apparently uniform land under the same treatment is often very surprising. An experiment in which duplicates agree as closely as could be desired is the exception rather than the rule. Cases in which the differences between plots treated alike are greater than between those treated differently, are, if anything, more common.

To get around this difficulty, numerous devices are employed. One is to test the uniformity of the plots by treating all alike the first year, and, if they vary materially, to either attempt to average duplicates so as to make the differences counterbalance, or to allow for the differences in computing the final results. One serious objection to either of these plans is the uncertainty as to the cause of the variation and to whether it will be constant in succeeding years.

Another plan consists in making the plots long and narrow, so as to equalize the differences. This, though often successful, is not always so. The ideal method would be to test the experimental areas by uniform treatment for a series of years until temporary causes of irregularity, such as came from manuring, tillage, cropping, &c., were eliminated, and to use for experiment only such as prove to be intrinsically uniform.

Where feasible, this latter plan is certainly to be recommended. But if we are to begin an experiment at once, doubtless the best way is to use small plots and duplicate the trials by using the same materials on several. This duplicating will test the uniformity and reliability of the whole experiment, and give averages which, when no untoward circumstances prevent, are pretty sure to be fairly satisfactory and are often perfectly so.

SIZE OF EXPERIMENTAL PLOTS.

Ordinarily, plots of eight square rods, one-twentieth acre, each, seem as satisfactory as any. In most cases, two plots of one-twentieth would be preferable to one of one-tenth acre. At least, such is the impression left on my mind after looking over the reports of several hundred experiments sent me for examination. Before this experience I was inclined to larger areas, but I have been surprised at the uniformity of small plots, when they are long and narrow. Some of the most satisfactory field experiments have been on plots of only four square rods. It is very common to leave a number of plots unmanured to test the uniformity of the soil, but it is a question whether this purpose is not better served by duplicating manured plots, and using not more than two or three unmanured for an ordinary experiment. Thus, for the nitrogen experiments, the most satisfactory plan I have found has been to leave one unmanured plot on each side of the experimental field, and to frequently duplicate the "basal mixture" of superphosphate and potash salt.

SPACES BETWEEN THE EXPERIMENTAL PLOTS.

Another frequent cause of inaccuracy in field experiments with fertilizers is the extension of the roots of the plants of one plot into the soil of the next one, so that the plants feed upon their neighbors' fertilizers. The roots of corn, for instance, extend laterally several feet, and, unless something is done to prevent, the plants may get so much material that does not belong to them as to vitiate the results of the experiments. The yield on an unmanured plot between two manured ones is often much larger than on another unmanured plot whose plants have not the fertilizers close at hand to draw upon. The best plan to obviate this is to leave unmanured strips between the experimental plot so wide that the roots will not reach across them. The difficulty can be helped, of course, by plowing between the plots deep enough to cut the roots.

NITROGEN EXPERIMENTS.

In planning these experiments we need to consider the questions to be studied, the forms and quantities of nitrogen to be used, and the most fitting arrangement for the experiments. The following details naturally suggest themselves:

A.—QUESTIONS ESPECIALLY NEEDING STUDY.

- I. The action of nitrogen in different forms and amounts upon the growth of plants under varying conditions of crop, soil, climate, season, &c.
- II. The feeding capacities of different plants as related to nitrogen, *i. e.*, their capacities for providing themselves with nitrogen

from natural sources, and for utilizing that furnished in the fertilizers, in so far as these capacities are indicated by effects of the nitrogenous materials upon their growth.

B.—FORMS AND AMOUNTS OF NITROGEN AND NITROGENOUS FERTILIZERS.

I. The most important forms of nitrogen are:

1. Nitric acid.
2. Ammonia.
3. Organic nitrogen.

II. Among the kinds of fertilizers containing nitrogen in these forms, the following are important:

- | | |
|--------------------------------|--------------------------------------|
| 1. Nitric acid. | 3. Organic nitrogen. |
| <i>a.</i> Nitrate of soda. | <i>a.</i> Dried blood. |
| <i>b.</i> Nitrate of potash. | <i>b.</i> Meat scrap. |
| 2. Ammonia. | <i>c.</i> Fish scrap and fish guano. |
| <i>a.</i> Sulphate of ammonia. | <i>d.</i> Leather scraps. |

III. Quantities, as above named, to wit, "one-twelfth," "one-sixth," "one-third," "two-thirds," and "full rations," or 6, 12, 24, 48, and 72 pounds per acre.

DETAILED PLANS.

In the account of nitrogen experiments above (pages 6, 8, and 9) are schedules of the kinds and quantities of fertilizing materials there employed. Judging from the results of past experience, however, those schedules would be improved by slightly altering the quantities so as to make them conform with the rations just named, and by enlarging the list of nitrogenous fertilizers to be tested.

KINDS OF NITROGENOUS FERTILIZERS.

The following will doubtless be to the purpose:

1. For nitric acid, nitrate of soda, 96 per cent. purity, with 16 per cent. nitrogen.
2. For ammonia, sulphate of ammonia, with 21 per cent. nitrogen.
3. For organic nitrogen.
 - a.* Dried blood (steam dried), with 11 per cent. nitrogen.
 - b.* Meat scrap, azotin, with 11 per cent. nitrogen.
 - c.* Fish guano, with 8 per cent. nitrogen.
 - d.* Leather scraps (finely pulverized), with 7 per cent. nitrogen.
4. For nitric acid, ammonia, and organic nitrogen together, "nitrogen mixture," consisting of nitrate of soda, 16 per cent. nitrogen; sulphate of ammonia, 21 per cent. nitrogen, and dried blood 11 per cent. nitrogen in equal parts, and containing 16 per cent., nitrogen.

QUANTITIES OF NITROGENOUS FERTILIZERS.

We may plan for each nitrogenous fertilizer a "group" with rations, as above suggested. Thus we may have nitrogen groups with quantities per acre as follows:

Nitrogen Rations.

	Ration.	Nitrate of soda.		Ration.	Sulphate of ammonia.
		<i>Pounds.</i>			<i>Pounds.</i>
NITRATE OF SODA GROUP	One-twelfth	38	SULPHATE OF AMMONIA GROUP	One-twelfth	29
	One-sixth	75		One-sixth	57
	One-third	150		One-third	114
	Two-thirds	300		Two-thirds	228
	Full	450		Full	343
	Ration.	Dried blood.		Ration.	Nitrogen mixture.
		<i>Pounds.</i>			<i>Pounds.</i>
DRIED BLOOD GROUP	One-twelfth	55	NITROGEN MIXTURE GROUP	One-twelfth	38
	One-sixth	110		One-sixth	75
	One-third	220		One-third	150
	Two-thirds	440		Two-thirds	300
	Full	660		Full	450

ARRANGEMENT OF THE EXPERIMENTS.

In this way such materials as may be most desirable can be selected for each experiment, and for each a group be used with all or part of the rations suggested. Future experience must show what quantities will be best. Probably, for ordinary crops in the North, the three largest rations will be well. In the South, for cotton, very likely the smaller will be preferable. At any rate, this flexibility of plan allows fair latitude of detail, and at the same time secures the uniformity needed for the tabulation and comparison of different experiments.

In some cases it will be desirable to use the nitrogenous fertilizers alone. In the majority of cases, however, the full effect of the nitrogen will not be manifested unless some other materials are added. Generally speaking, the experiment will be most satisfactory with "complete fertilizers," such as can be made by adding the nitrogenous materials to a mixture of superphosphate and potash salt, which may be designated as "mineral fertilizers" or "mixed minerals." For these, the two-thirds rations, 400 pounds of superphosphate and 133 pounds of muriate of potash, will probably be adapted to a larger proportion of the soils and crops than the mixture of 300 pounds of superphosphate and 150 pounds of muriate of potash, used in the former nitrogen experiments. Taking the basal mixture named, and adding the several rations of nitrate of soda we shall have a "Nitrate of Soda Group" of five mixtures, each mixture containing the "mixed minerals" with a nitrate of soda ration as below:

Nitrate of Soda Group:

Mixed minerals with nitrate of soda, one-twelfth ration.

Mixed minerals with nitrate of soda, one-sixth ration.

Mixed minerals with nitrate of soda, one-third ration.

Mixed minerals with nitrate of soda, two-thirds ration.

Mixed minerals with nitrate of soda, full ration.

The amount per acre and the percentages of the several ingredients in the nitrogen mixture group, for instance, would be as follows :

	Fertilizing materials.			Ingredients.					
	Superphosphate, pounds per acre.	Muriate of potash, pounds per acre.	Nitrogen mixture, pounds per acre.	Phosphoric acid, pounds per acre.	Potash, pounds per acre.	Nitrogen, pounds per acre.	Phosphoric acid, per cent.	Potash, per cent.	Nitrogen, per cent.
Nitrogen mixture group.									
One-twelfth ration	400	133	38	64	67	6	11.2	11.7	1.5
One-sixth ration	400	133	75	64	67	12	10.5	11.0	2.0
One-third ration	400	133	150	64	67	24	9.3	9.8	3.5
Two-thirds ration	400	133	300	64	67	48	7.6	8.0	5.8
Full ration	400	133	450	64	67	72	6.5	6.8	7.3

PRELIMINARY GROUP.

The experiment will be much more satisfactory if we know the effects of the superphosphate, potash, salt, and nitrogenous materials separately, and, inferentially, the capacity of the soil to supply the phosphoric acid and potash as well as the nitrogen. To this end we may use the materials separately, and two by two, as has been done in previous experiments, and is shown in the schedule beyond. In the experiments described above the nitrogen of the preliminary groups has been supplied in either nitrate of soda or "nitrogen mixture." Though experience has shown very little difference, probably the mixture will be the safer, and accordingly it is here recommended.

As urged above, the many sources of error in field experiments make duplicates very important. This may be effected by repeating the nitrogen groups, in which opportunity is taken to test the different forms of nitrogen, and by putting the mixed minerals on each side of each nitrogen group, thus testing the uniformity of the soil, replacing the unmanured plots, and showing more accurately the effects of the nitrogen.

To recapitulate briefly, our experimental fertilizers, as thus planned, will be arranged in groups, thus :

Partial fertilizers	Preliminary Group. Each by itself, and two by two. Thus testing the effects of ingredients separately and capacity of soil to sup- ply them.
Complete Fertilizers.	Nitrate of soda Group. Nitrogen as nitric acid in nitrate of soda. Sulphate of ammonia Group. Nitrogen as ammonia in sulphate of ammonia. Dried blood Group. Nitrogen as organic nitrogen in dried blood. Nitrogen mixture Group. Nitrogen in the three forms named above. Nitrogen in one-twelfth, one- sixth, one-third, two-thirds, and full rations.

Other groups containing meat scrap, fish guano, Peruvian guano, leather scrap, &c., can be employed at the discretion of the experimenter. When desired, as may be the case with cotton, for instance,

half the quantities may be used, or the same quantities distributed over double the area. The preliminary groups can be omitted if necessary, the nitrogen groups used without the basal mixture, and a smaller list of rations used in each group, as may be desirable in each case. Two nitrogen sets, which can be obtained ready for use, are described beyond.

PHOSPHORIC ACID EXPERIMENTS.

In devising plans for these experiments we have to consider what questions are to be studied and what compounds of phosphoric acid are to be employed.

A.—QUESTIONS TO BE STUDIED.

The following may be regarded, at the outset at least, as among the more important:

- I. The action of phosphoric acid in different forms and amounts upon the growth of plants under different conditions of crop, soil, climate, season, &c., *e. g.*,
 1. Soluble *vs.* precipitated.
 2. Soluble *vs.* insoluble.
 3. Effects of fineness of pulverization upon the availability of insoluble phosphoric acid in bone, rock phosphate, &c.
 4. Bone *vs.* mineral phosphate.
 5. Raw bone *vs.* boiled bone; *i. e.*, bone from which gelatine has been extracted.
- II. The feeding capacities of different plants as related to phosphoric acid, *i. e.*, their capabilities of availing themselves of the supplies of phosphoric acid at their disposal in the soil, and in fertilizers, in so far as their capabilities are indicated by the observed effects of the phosphoric acid compounds.

B.—FORMS AND AMOUNTS OF PHOSPHORIC ACID AND PHOSPHATIC COMPOUNDS.

The following list seems complete enough for the present purpose:

- I. Forms of phosphoric acid :
 1. Soluble.
 2. Precipitated.
 3. Insoluble.
- II. Kinds of phosphatic compounds :
 1. Bone.
 - a.* Raw.
 - b.* Steamed.
 - c.* Bone black.
 - d.* Bone ash.
 2. Phosphatic guanos.
 - a.* Curaçoa, &c.

3. Mineral or rock phosphate.

a. South Carolina.

b. Navassa.

c. Apatite, &c.

III. Grades of fineness: The grades of fineness will naturally depend upon what the market affords. We might use, for instance:

1. Coarse.

2. Medium.

3. Fine.

IV. Quantities of phosphoric acid:

Each of the several forms may be used in different "rations," the several rations making a group, as in the nitrogen experiments.

DETAILED PLANS.

For the specific materials to furnish the phosphoric acid in the soluble and precipitated forms, the following are perhaps as well fitted for the purpose as any. Of course others will suggest themselves.

1. Soluble phosphoric acid:

a. Dissolved bone black with 16 per cent. P_2O_5 .b. High-grade superphosphate with 32 per cent. P_2O_5 .

Of the above, perhaps (a) will serve best to begin with.

2. Precipitated phosphoric acid. This may consist of—

a. High-grade superphosphate with equal weights of chalk, making a precipitated phosphate with 16 per cent. P_2O_5 .

3. Insoluble phosphoric acid. For this, bone, phosphatic guanos, and mineral or rock phosphates will be in order. Bone and South Carolina phosphate are perhaps the most important at present:

a. Fine bone dust (mesh, 40.) from steamed or raw bone with 25 per cent. P_2O_5 .b. South Carolina phosphate with 25 per cent. P_2O_5 .

QUANTITIES OF PHOSPHORIC ACID.

As already suggested we may arrange for each of the phosphatic compounds a group of four rations. Below are examples with quantities per acre:

	Ration.	Dissolved bone black.		Ration.	Precipitated super-phosphate.
		Pounds.			Pounds.
SUPERPHOSPHATE GROUP.	a. One-sixth.....	100	PRECIPITATED PHOSPHATE GROUP.	a. One-sixth.....	100
	b. One-third.....	200		b. One-third.....	200
	c. Two-thirds.....	400		c. Two-thirds.....	400
	d. Full.....	600		d. Full.....	600

	Ration.	South Carolina superphosphates.		Ration	Steamed bone.
		<i>Pounds.</i>			<i>Pounds.</i>
SOUTH CAROLINA SUPERPHOS- PHATE GROUP. {	d. One-sixth.....	133	STEAMED BONE GROUP. {	a. One-sixth	67
	b. One-third.....	267		b. One-third.....	133
	c. Two-thirds....	533		c. Two-thirds ...	267
	a. Full.....	800		d. Full.....	400

The effects of fineness of pulverization may be tested by such groups as these :

	Grade of fineness.	Ground bone.		Grade of fineness.	Phosphate.
		<i>Pounds.</i>			<i>Pounds.</i>
FINE, MEDIUM, AND COARSE BONE DUST GROUP. {	Fine.....	400	FINE, MEDIUM, AND COARSE S. C. PHOSPHATE GROUP. {	Fine.....	400
	Medium.....	400		Medium.....	400
	Coarse.....	400		Coarse.....	400

The details of quantities per acre and percentages of the Superphos. phate group, for instance, will be :

SUPERPHOSPHATE GROUP.	Fertilizing materials.			Ingredients.					
	Nitrogen mixture, pounds per acre.	Muriate of potash, pounds per acre.	Superphosphate, pounds per acre.	Nitrogen, pounds per acre.	Potash, pounds per acre.	Phosphoric acid, pounds per acre.	Nitrogen, per cent.	Potash, per cent.	Phosphoric acid, per cent.
A, One-sixth ration.....	150	133	100	24	67	16	6.3	17.3	4.9
B, One-third ration.....	150	133	200	24	67	32	5.0	13.9	6.7
C, Two-thirds ration	150	133	400	24	67	64	3.5	9.8	9.4
D, full ration	150	133	600	24	67	96	2.7	7.6	10.9

That is to say, the Superphosphate Group would thus consist of four mixtures. Each of these mixtures will contain a "basal mixture" with nitrogen and potash each in $\frac{2}{3}$ ration (see page 20). To this basal mixture the super-phosphate is added in successive amounts, from "one-sixth ration" to "full ration," or from 16 to 96 pounds per acre.

SULPHATE OF LIME GROUP.

Since more or less of the effect of the superphosphate may be due to its sulphate of lime, a check trial with plaster as provided in the schedule on page 31 may be advisable.

The explanation of the nitrogen experiment will apply, *mutatis mutandis*, to the phosphoric acid experiment. The idea is to so arrange the

materials that each experimenter may select groups or parts of groups at his discretion and thus make up such an experiment as will be most to the purpose in the conditions under which he works.

The following list of materials and groups includes perhaps the most important, and suggests a schedule of experimental fertilizers:

Partial Fertilizers ...	{ Preliminary Group, each by itself, and two by two.	{ Thus testing the effects of ingredients separately, and capacity of soil to sup- ply them.
Complete Fertilizers.	{ Soluble phosphoric acid Group. Precipitated phosphoric acid Group. Insoluble phosphoric acid Group. Steamed bone. Insoluble phosphoric acid Group. Raw bone. Insoluble phosphoric acid Group. S. C. phosphate. Sol., Precip., and Insol. Phos. acid Group. S. C. super- phosphate. Etc., etc.	{ Phosphoric acid in one-sixth ration, one-third ration, two-thirds ration, and full ration.
	{ Raw bone Group. South Carolina phosphate Group. Etc., etc., etc.	{ Different grades of fineness.

SCHEDULES FOR EXPERIMENTS.

While experimenters will arrange their experiments at discretion, it has seemed to me desirable to suggest schedules, and, if practicable, to make arrangements to assist them in procuring the materials with the least trouble and expense. I have, therefore, drawn up schedules for three sets of experimental fertilizers, as follows:

The first, "*Nitrogen Set No. 1*," is nearly the same as used by a number of gentlemen last season. Nitrogen is supplied as nitric acid, ammonia, and organic nitrogen, in three groups with three rations, $\frac{1}{3}$, $\frac{2}{3}$, and full ration, in each. The set requires 18 plots for the fertilizers, which, with two unmanured, would make 20 plots, or, with one-twentieth acre plots, one acre of land, for the experiment. With spaces between the plots a larger area will be needed.

NITROGEN SET NO. 1.

Materials.		Amounts.	
		Acre set—for one-twentieth acre plots.	Two-acre set—for one-tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
Preliminary Group ..	1. Nitrate of soda, one-third ration	7.5	15.0
	2. Superphosphate	20.0	40.0
	3. Muriate of potash	6.7	13.3
	4. { Nitrate of soda, one-third ration	7.5	15.0
	{ Superphosphate	20.0	40.0
	5. { Nitrate of soda, one-third ration	7.5	15.0
Nitrate of soda Group	{ Muriate of potash	6.7	13.3
	6. { Superphosphate. } Mixed minerals. {	20.0	40.0
	{ Muriate of potash }	6.7	13.3
Nitrate of soda Group	7. { Mixed minerals, as No. 6	26.7	53.3
	{ Nitrate of soda, one-third ration	7.5	15.0
	8. { Mixed minerals, as No. 6	26.7	53.3
	{ Nitrate of soda, two-thirds ration	15.0	30.0
	9. { Mixed minerals, as No. 6	26.7	53.3
	{ Nitrate of soda, full ration	22.5	45.0
	6a. Mixed minerals, as No. 6	26.7	53.3

NITROGEN SET No. 1—Continued.

Materials.		Amounts.	
		Acres set— for one-twentieth acre plots.	Two-acre set— for one-tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
Sulphate of ammonia Group.	10. { Mixed minerals, as No. 6	26.7	53.3
	{ Sulphate of ammonia, one-third ration	5.6	11.3
	11. { Mixed minerals, as No. 6	26.7	53.3
	{ Sulphate of ammonia, two-thirds ration	11.3	22.5
	12. { Mixed minerals, as No. 6	26.7	53.3
	{ Sulphate of ammonia, full ration	16.8	33.7
	6b. Mixed minerals, as No. 6	26.7	53.3
Dried blood Group ..	13. { Mixed minerals, as No. 6	26.7	53.3
	{ Dried blood, one-third ration	11.0	22.0
	14. { Mixed minerals, as No. 6	26.7	53.3
	{ Dried blood, two-thirds ration	22.0	44.0
	15. { Mixed minerals, as No. 6	26.7	53.3
	{ Dried blood, full ration	33.0	66.0
	6c. Mixed minerals, as No. 6	26.7	53.3

The following, "*Nitrogen Set No. 2*," is simpler, containing only the preliminary group, and a nitrogen mixture group with five rations, and one extra "mixed minerals." It has the advantage of greater simplicity, and of testing the effects of smaller quantities of nitrogen, but has the disadvantage of not duplicating the nitrogen tests. It can be greatly improved by duplicating the "nitrogen mixture" group, which, with an extra "mixed minerals," will make 18 fertilizers. With one-twentieth acre plots, this would require an acre, and make an excellent experiment.

NITROGEN SET NO. 2.

Materials.		Amounts.	
		Set— for one- twentieth acre plots.	Set— for one- tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
Preliminary Group...	1. Nitrogen mixture, one-third ration	7.5	15.0
	2. Superphosphate	20.0	40.0
	3. Muriate of potash	6.7	13.3
	4. { Nitrogen mixture, one-third ration	7.5	15.0
	{ Superphosphate	20.0	40.0
	5. { Nitrogen mixture, one-third ration	7.5	15.0
Nitrogen mixture Group.	{ Muriate of potash	6.7	13.3
	6. { Superphosphate	20.0	40.0
	{ Muriate of potash	6.7	13.3
	7. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, one-twelfth ration	1.9	3.8
	8. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, one-sixth ration	3.7	7.5
	9. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, one-third ration	7.5	15.0
	10. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, two-thirds ration	15.0	30.0
	11. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, full ration	22.5	45.0
	6a. Mixed minerals	26.7	53.3

The following specifications are intended for use in ordering the fertilizers:

Specifications for nitrogen sets: Materials to be weighed and mixed with greatest possible care and accuracy, put in bags, and each bag furnished with a label stating number and contents per schedule. *Minimum* percentages as follows: Nitrate of soda, 16 per cent. nitrogen; sulphate of ammonia, 21 per cent. nitrogen; dried blood, 11 per cent. nitrogen; superphosphate (dissolved bone black) 15 per cent. soluble and 16 per cent. total phosphoric acid; muriate of potash, 50 per cent. potash.

PHOSPHORIC ACID SET.

This tests the action of soluble phosphoric acid, in dissolved bone black, precipitated phosphoric acid in a mixture of high grade superphosphate from bone and chalk, and insoluble phosphoric acid in bone from which the larger part of the organic matter has been removed. A sulphate of lime group is added as a test of the effect of the sulphuric acid and lime of the superphosphates. This includes 25 fertilizers, which with two unmanured plots would require 27 plots, or if each plot is one-twentieth acre, a little over $1\frac{1}{2}$ acres, and more if unmanured strips are left between the rows. The set can be reduced to 21 by omitting the sulphate of lime group, and to 18 by using only three rations in each phosphoric acid group.

PHOSPHORIC ACID SET.

Materials.		Amounts.		
		Regular size for one-twentieth acre plots.	Double size for one-tenth acre plots.	
		Pounds.	Pounds.	
Preliminary Group..	A.	Nitrogen mixture	7.5	15.0
	B.	Superphosphate	20.0	40.0
	C.	Muriate of potash	6.7	13.3
	D.	{ Nitrogen mixture	7.5	15.0
		{ Superphosphate	20.0	40.0
	E.	{ Muriate of potash	6.7	13.3
		{ Superphosphate	20.0	40.0
	F.	{ Nitrogen mixture } Basal mixture {	7.5	15.0
{ Muriate of potash }		6.7	13.3	
Soluble phosphoric acid Group.	A.	{ Basal mixture	14.2	28.3
		{ Dissolved bone black	5.0	10.0
	B.	{ Basal mixture	14.2	28.3
		{ Dissolved bone black	10.0	20.0
	C.	{ Basal mixture	14.2	28.3
		{ Dissolved bone black	20.0	40.0
	D.	{ Basal mixture	14.2	28.3
		{ Dissolved bone black	30.0	60.0
Fa. Basal mixture		14.2	28.3	
Precipitated phosphoric acid Group.	A.	{ Basal mixture	14.2	28.3
		{ Precipitated phosphate	5.0	10.0
	B.	{ Basal mixture	14.2	28.3
		{ Precipitated phosphate	10.0	20.0
	C.	{ Basal mixture	14.2	28.3
		{ Precipitated phosphate	20.0	40.0
	D.	{ Basal mixture	14.2	28.3
		{ Precipitated phosphate	30.0	60.0
Fb. Basal mixture		14.2	28.3	

PHOSPHORIC ACID SET—Continued.

Materials.		Amounts.	
		Regular size for one-tenth acre plots.	Double size for one-tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
Steamed bone Group.	A. { Basal mixture	14.2	28.3
	{ Bone dust	5.0	10.0
	B. { Basal mixture	14.2	28.3
	{ Bone dust	10.0	20.0
	C. { Basal mixture	14.2	28.3
	{ Bone dust	20.0	40.0
	D. { Basal mixture	14.2	28.3
	{ Bone dust	30.0	60.0
	Fe. Basal mixture	14.2	28.3
Sulphate of lime Group.	A. { Basal mixture	14.2	28.3
	{ Plaster	3.8	7.5
	B. { Basal mixture	14.2	28.3
	{ Plaster	7.5	15.0
	C. { Basal mixture	14.2	28.3
	{ Plaster	11.3	22.5
	Fd. Basal mixture	14.2	28.3

Besides the above set, groups like the following may be employed.

Materials.		Amounts.	
		Regular size for one-tenth acre plots.	Double size for one-tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
South Carolina super- phosphate Group.	A. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	6.7	13.3
	B. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	13.3	26.7
	C. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	26.7	53.4
	D. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	40.0	80.0
South Carolina phos- phate Group.	A. { Basal mixture	14.2	28.3
	{ South Carolina phosphate		
	B. { Basal mixture	14.2	28.3
	{ South Carolina phosphate		
	C. { Basal mixture	14.2	28.3
Steamed bone Group.	D. { Basal mixture	14.2	28.3
	{ Steamed bone		
	A. { Basal mixture	14.2	28.3
	{ Steamed bone	5.0	10.0
	B. { Basal mixture	14.2	28.3
Fine, medium, and coarse bone Group.	{ Steamed bone	10.0	20.0
	C. { Basal mixture	14.2	28.3
	{ Steamed bone	20.0	40.0
	D. { Basal mixture	14.2	28.3
	{ Steamed bone	30.0	60.0
Fine, medium, and coarse South Caroli- na phosphate Group.	A. { Basal mixture	14.2	28.3
	{ Ground bone (fine)	20.0	40.0
	B. { Basal mixture	14.2	28.3
	{ Ground bone (medium)	20.0	40.0
	C. { Basal mixture	14.2	28.3
	{ Ground bone (coarse)	20.0	40.0
	A. { Basal mixture	14.2	28.3
	{ South Carolina phosphate (fine)	20.0	40.0
	B. { Basal mixture	14.2	28.3
	{ South Carolina phosphate (medium)	20.0	40.0
	C. { Basal mixture	14.2	28.3
	{ South Carolina phosphate (coarse)	20.0	40.0

Specifications for fertilizers of phosphoric acid set: Materials to be put up with greatest care, in bags with labels stating contents. Minimum percentages as follows: Nitrogen mixture and muriate of potash as in nitrogen experiment. Superphosphate (dissolved bone black) with 15 per cent. soluble, and 16 per cent. total P_2O_5 . Precipitated phosphate to consist of high grade superphosphates 32 per cent. and chalk in equal parts, and to contain 16 per cent. P_2O_5 . Other materials to be of good average quality.

ARRANGEMENT OF THE EXPERIMENT.

The plan herewith shows a fitting arrangement for the "Nitrogen Experiment No. 1," and illustrates how others may advantageously be planned.

NITROGEN EXPERIMENT.

Arrangement of experimental field.

With "Acre set." Each plot $\frac{1}{20}$ acre.	} Or more with unmanured strips between each two plots.
Whole field one acre.	
With "Two-acre set." Each plot $\frac{1}{10}$ acre.	
Whole field two acres.	

- | | | |
|------------------------|---|---|
| Preliminary group..... | { | 0. No manure. |
| | | 1. Nitrate of soda. |
| | | 2. Superphosphate. |
| | | 3. Muriate of potash. |
| | | 4. Nitrate of soda and superphosphate. |
| | | 5. Nitrate of soda and muriate of potash. |
| Nitric-acid group..... | { | 6. Superphosphate and muriate of potash. |
| | | "Mixed minerals." |
| | | 7. Mixed minerals plus nitrate of soda. One-third ration. |
| | | 8. Mixed minerals plus nitrate of soda. Two-thirds ration. |
| Ammonia group..... | { | 9. Mixed minerals plus nitrate of soda. Full ration. |
| | | 6a. Mixed minerals. Duplicate of No. 6. |
| | | 10. Mixed minerals plus sulphate of ammonia. One-third ration. |
| | | 11. Mixed minerals plus sulphate of ammonia. Two-thirds ration. |
| Organic-nitrogen group | { | 12. Mixed minerals plus sulphate of ammonia. Full ration. |
| | | 6b. Mixed minerals. Duplicate of No. 6. |
| | | 13. Mixed minerals plus dried blood. One-third ration. |
| | | 14. Mixed minerals plus dried blood. Two-thirds ration. |
| | { | 15. Mixed minerals plus dried blood. Full ration. |
| | | 6c. Mixed minerals. Duplicate of No. 6. |
| | | 60. No manure. |

CROPS TO BE EXPERIMENTED UPON.

The kind of crop will, of course, be selected by the experimenter. Experiments are needed upon all our ordinary crops, but especially on wheat, barley, rye, oats, corn, sorghum, grass, clover, onions, potatoes, roots, and, in the South, sugar cane and cotton.

3 A



